



The Use of Virtual Laboratories and Immersive Technology in Science Education in the Digital Era

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ABSTRACT

This study aims to explore the use of virtual laboratories and immersive technologies, such as Virtual Reality (VR) and Augmented Reality (AR), in science education in the digital era. These technologies are believed to enhance student engagement, facilitate the understanding of complex concepts, and overcome the limitations of physical laboratories. The study employed a Systematic Literature Review (SLR) method by analyzing 13 selected articles from 574 initially identified studies in the Scopus and Scimago databases, published between 2015 and 2025. The analysis involved thematic coding, synthesis of findings, and comparison of research results to identify the benefits, challenges, and implementation trends. The findings indicate that virtual laboratories and immersive technologies can increase learning motivation, provide safe and flexible experimental experiences, and deepen the understanding of scientific concepts. However, challenges such as limited infrastructure, high costs of equipment procurement, and the need for teacher training remain significant obstacles. This study concludes that integrating virtual laboratories and immersive technologies has great potential to enrich science learning but requires policy support, infrastructure development, and enhanced teacher competencies. The implications emphasize the need for collaboration among educational institutions, policymakers, and technology providers to optimize their application in science education.

Keywords: Virtual laboratories, Immersive technology, Augmented Reality, Virtual Reality, Science education, Digital learning

Penggunaan Laboratorium Virtual dan Teknologi Imersif dalam Pembelajaran Sains di Era Digital

ABSTRAK

Penelitian ini bertujuan mengeksplorasi pemanfaatan laboratorium virtual dan teknologi imersif, seperti Virtual Reality (VR) dan Augmented Reality (AR), dalam pembelajaran sains di era digital. Teknologi ini diyakini mampu meningkatkan keterlibatan siswa, memfasilitasi pemahaman konsep yang kompleks, serta mengatasi keterbatasan laboratorium fisik. Metode yang digunakan adalah Systematic Literature Review (SLR) dengan menganalisis 13 artikel terpilih dari 574 artikel yang ditemukan pada basis data Scopus dan Scimago, terbit antara 2015–

2025. Analisis dilakukan melalui pengkodean tema, sintesis temuan, dan perbandingan hasil penelitian untuk mengidentifikasi manfaat, tantangan, dan tren implementasi. Hasil menunjukkan bahwa laboratorium virtual dan teknologi imersif dapat meningkatkan motivasi belajar, memberikan pengalaman eksperimen yang aman dan fleksibel, serta memperdalam pemahaman konsep sains. Namun, hambatan berupa keterbatasan infrastruktur, tingginya biaya pengadaan perangkat, dan kebutuhan pelatihan guru masih menjadi kendala utama. Penelitian ini menyimpulkan bahwa integrasi laboratorium virtual dan teknologi imersif berpotensi memperkaya pembelajaran sains, tetapi memerlukan dukungan kebijakan, pengembangan infrastruktur, dan peningkatan kompetensi pendidik. Implikasi dari hasil penelitian ini menegaskan perlunya kolaborasi antara institusi pendidikan, pemerintah, dan penyedia teknologi untuk mengoptimalkan pemanfaatannya dalam pendidikan sains.

Kata kunci: Laboratorium virtual, Teknologi imersif, Realitas Tertambah, Realitas Virtual, Pendidikan sains, Pembelajaran digital

INTRODUCTION

The development of technology in education, particularly in science learning, has had a significant impact (Dasopang, 2021; Timotheou et al., 2023). Information and communication technology (ICT) provides broader and more effective access to learning resources, introducing deeper science concepts through visual, interactive media, and simulations. One notable advancement is the use of virtual laboratories and immersive technologies such as virtual reality (VR) and augmented reality (AR) (Al-Ansi et al., 2023; Xiong et al., 2021). These technologies allow students to experience laboratory practices that were previously difficult to access due to limitations in equipment or space. For instance, with VR technology, students can interact with 3D models representing molecular structures or complex natural phenomena, offering a more immersive and interactive learning experience (Brown et al., 2021).

This technology also supports safer and more cost-effective experiment-based learning. Science education using immersive technologies, such as virtual laboratories, allows students to conduct chemistry or physics experiments without the risks typically associated with physical laboratories (Ali et al., 2022; Bogusevschi et al., 2020). Previous studies have shown that the use of technologies like VR in science education enhances student engagement and facilitates a better understanding of complex scientific concepts (Christopoulos et al., 2018; Lindgren et al., 2016; Liu et al., 2020). Moreover, this technology offers greater flexibility for educators to tailor the teaching material to meet students' needs and abilities, creating a more personalized and effective learning experience.

A virtual laboratory is a digital platform that allows students to conduct science experiments without the need to be in a physical laboratory. In a virtual laboratory, users can interact with simulations of objects or experiments that reflect existing scientific concepts, enabling them to understand scientific principles in a more in-depth and practical way (Alnagrat et al., 2022; Pellas et al., 2021). This technology utilizes software that simulates various experiments, which typically require expensive or high-risk physical equipment. Virtual laboratories help students explore and practice difficult-to-understand concepts in a safe environment, providing a more engaging and efficient learning experience (Caño de las Heras et al., 2021). Additionally, this technology allows

experiments to be conducted repeatedly with varying parameters, offering opportunities for deeper exploration.

Immersive technologies such as augmented reality (AR), virtual reality (VR), and mixed reality (MR) create deeper learning experiences by merging the physical and digital worlds (Kuhail et al., 2022; Liberatore & Wagner, 2021; Pellas et al., 2020). Virtual reality (VR) creates a fully immersive 3D environment where users can interact with digital objects in a world completely separate from the physical one. Augmented reality (AR) adds digital elements to the real world, enhancing the learning experience by overlaying visual information in the context of the real environment (AlGerafi et al., 2023; Dargan et al., 2023). Mixed reality (MR) combines elements of AR and VR, enabling more complex interactions between physical and virtual objects (Rokhsaritalemi et al., 2020). The use of AR, VR, and MR technologies in science education can enhance the understanding of scientific concepts in a more visual and interactive manner, as well as increase student engagement in the learning process (Fisher & Baird, 2020; Ö. Yılmaz, 2023).

The importance of utilizing technology in science education in the digital era is immense, as it enriches the learning experience, increases student engagement, and addresses the limitations of conventional teaching methods (Adiyono et al., 2024; Haleem et al., 2022). Technologies such as virtual laboratories, augmented reality (AR), and virtual reality (VR) provide students with the opportunity to interact directly with scientific concepts that are often difficult to grasp through theory alone. These technologies enable more visual and immersive learning, which can enhance students' understanding and retention of the material being taught (Hariyono, 2023; Iskandar et al., 2023). The use of technology in science education not only makes the material more engaging but also helps students connect theory with practical applications, thereby improving the quality of their understanding (Zhai, 2021). Thus, these technologies serve as tools that expand the horizons of learning beyond the constraints of physical space and time.

The use of technology also helps prepare students to face the challenges of a workforce increasingly dominated by digital technologies (Ahmad, 2020). In the context of science education, this technology enables more flexible teaching that can be adapted to various student learning styles. The use of immersive technologies such as VR and AR allows students to conduct experiments that may not be feasible in the real world due to resource limitations or safety concerns (Fitrianto & Saif, 2024). This is particularly important as it enhances students' practical skills and critical thinking abilities. The integration of technology in science education not only supports mastery of the material but also fosters the development of essential 21st-century skills such as creativity, critical thinking, and collaboration (Fadillah, 2024; A. Yılmaz, 2021).

METHOD

This study employs the Systematic Literature Review (SLR) method. SLR is a research method used to systematically and transparently identify, select, and analyze relevant literature (Mohamed Shaffril et al., 2021; Sauer & Seuring, 2023; Van Dinter et al., 2021). The purpose of SLR is to collect and synthesize existing research findings, provide a comprehensive overview of a specific topic or phenomenon, and identify trends, knowledge gaps, and areas for further research (Valverde-Berrocso et al., 2020). In this study, inclusion and exclusion criteria are used to determine which articles are suitable to be included in the analysis as shown in Table 1.

Table 1. Inclusion and Exclusion Criteria

<i>Inclusion</i>	<i>Exclusion</i>
Articles published between 2015-2025.	Articles published before 2015 or after 2025.
Focus on the use of virtual laboratories and immersive technologies (AR, VR, MR) in the context of science education.	Articles that only discuss technology for fields other than education or science.
Articles that use empirical data to support the findings of the research.	Articles that do not use empirical data but only theoretical reviews to validate experiments.
Articles relevant to science education across various educational levels, from elementary to higher education.	Articles that do not discuss technology in the context of education or are not relevant to science education.

The search procedure was conducted using the Scopus database, which is internationally recognized as one of the primary sources for academic literature. The literature search involved the following steps: 1) Searching using relevant keywords, such as "Virtual laboratory," "Immersive technology," "Science education," "Virtual Reality in education," "Augmented Reality in education," and "Mixed Reality in science education." 2) Using filters to limit the search results to articles published between 2015 and 2025. 3) An initial evaluation of the titles, abstracts, and keywords of the articles to ensure their relevance to the research topic.

The article selection process is carried out in several stages: First, articles are identified based on relevance by reviewing their titles and abstracts. Articles that are not directly related to the research topic or do not meet the inclusion criteria are excluded. Next, the selected articles are further evaluated based on the quality of their methodology and the data used, with priority given to experimental designs, case studies, or applied research. Articles that consist only of opinions or analyses without empirical data are excluded. Finally, two independent researchers will verify the selected articles to ensure they meet both inclusion and exclusion criteria and minimize bias in the literature selection process.

After the relevant articles are selected, the data contained in the articles will be analyzed qualitatively to identify the key themes related to the application of virtual laboratories and immersive technologies in science education. The data analysis process involves the following steps: 1) Theme Coding: The selected articles will be analyzed to identify emerging themes related to the benefits, challenges, and impacts of using technology in science education. These thematic codes include categories such as "impact on student engagement," "learning effectiveness," "technology accessibility," and "implementation challenges." 2) Synthesis of Findings: Findings from various articles will be synthesized to provide an overview of the role and impact of virtual laboratories and immersive technologies in science education. The analysis will focus on the contribution of technology to enhancing students' understanding of scientific concepts and its impact on student engagement and motivation. 3) Comparison and Contradictions: Different studies will be compared to assess the consistency or discrepancies in the findings and to identify gaps or unresolved questions in the existing literature.

RESULT AND DISCUSSION

The research data used in this Systematic Literature Review process consists of an analysis of documented articles. In this meta-analysis, the researcher examines 13 articles indexed in Scopus and Scimago regarding the use of virtual laboratories and immersive technologies in science education in the digital era. The analysis includes detailed information about the publication year, author biographies, and citation counts of the reviewed articles. The analysis of the 13 articles that meet the inclusion criteria is presented in Table 2.

Code	Title (Author, Year)	Source	Total citation
A1	<i>A model for augmented reality immersion experiences of university students studying in science education</i> (Salar et al., 2020)	<i>Journal of Science and Technology</i>	106
A2	<i>Virtual and remote labs in education: A bibliometric analysis</i> (Heradio et al., 2016)	<i>Computers & Education</i>	779
A3	<i>Barriers to the Adoption of Augmented Reality Technologies for Education and Training in the Built Environment: A Developing Country Context.</i> (Akinradewo et al., 2025)	<i>Technologies</i>	3
A4	<i>Integrating immersive technologies with STEM education: a systematic review.</i> <i>Frontiers in Education</i> (Tene et al., 2024)	<i>Frontiers in Education</i>	25
A5	<i>Integration of Virtual Labs in Science Education: A Systematic Literature Review</i> (Rosli & Ishak, 2024)	Jurnal Pendidikan Sains Dan Matematik Malaysia	3
A6	<i>Virtual Reality as a Pedagogical Tool: Motivation and Perception in Teacher Training for Social Sciences and History in Primary Education</i> (Villena-Taranilla et al., 2025)	<i>Education Sciences</i>	1
A7	<i>The impact of virtual reality on practical skills for students in science and engineering education: a meta-analysis</i> (Yang et al., 2024)	<i>International Journal of STEM Education</i>	20
A8	<i>Virtual laboratories for education in science, technology, and engineering: A review</i> (Potkonjak et al., 2016)	<i>Computers & Education</i>	1349
A9	<i>Impact of immersing university and high school students in educational linear narratives using virtual reality technology</i> (Calvert & Abadia, 2020)	<i>Computers & Education</i>	241
A10	<i>Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills</i> (Papanastasiou et al., 2019)	<i>Virtual Reality</i>	570
A11	<i>Immersive virtual reality and augmented reality in anatomy education: A systematic review and meta-analysis.</i> <i>Anatomical Sciences Education</i> (García-Robles et al., 2024)	<i>Anatomical Sciences Education</i>	43

Code	Title (Author, Year)	Source	Total citation
A12	<i>Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective</i> (Alalwan et al., 2020)	<i>Studies in Educational Evaluation</i>	384
A13	<i>Teaching in a Digital Age: How Educators Use Technology to Improve Student Learning</i> (McKnight et al., 2016)	<i>Journal of Research on Technology in Education</i>	968

We will examine the key findings derived from the literature analysis regarding the use of virtual laboratories and immersive technologies in science education. Based on existing studies, these technologies have shown a significant positive impact on the learning process, especially in providing deeper, more interactive, and safer learning experiences. For instance, virtual laboratories allow students to conduct experiments that are difficult or hazardous to perform in real-world settings, offering opportunities for broader exploration without risk. This is crucial in enhancing students' understanding of complex scientific concepts (Salar et al., 2020).

On the other hand, immersive technologies such as augmented reality (AR) and virtual reality (VR) have proven to increase student engagement and motivation in learning. With these technologies, students not only gain theoretical knowledge but also experience it in a visual and interactive manner. These technologies not only enrich the learning experience but also address the limitations of conventional teaching methods, particularly in terms of accessibility and cost (Heradio et al., 2016).

There are several challenges in implementing these technologies, such as technical constraints, limited resources, and the need for training educators to optimally utilize these technologies. Furthermore, it is important to note that while these technologies offer great potential, their effectiveness still depends on the educational context and the way they are applied. Therefore, further studies and systematic evaluations of the use of immersive technologies in science education are necessary to ensure that their implementation maximizes the learning outcomes for students (Salar et al., 2020; Heradio et al., 2016).

The implementation of technology in education faces several challenges. One major issue is infrastructure limitations, as many schools or universities, particularly in developing countries, struggle to provide the necessary hardware and software to support the use of VR, AR, or virtual laboratories (Akinradewo et al., 2025). This limitation can hinder the adoption of technology, even though it has the potential to greatly improve education quality. Another challenge is the lack of teacher training, as many educators are not adequately prepared to integrate these technologies into their teaching. Therefore, comprehensive training and professional development for teachers are essential to ensure that these technologies can be effectively utilized to support science education (Tene et al., 2024).

Immersive technologies and virtual laboratories have proven to significantly impact students' understanding of scientific concepts. First, Improved Understanding of Scientific Concepts: These technologies help students grasp abstract or difficult-to-explain concepts that cannot be fully conveyed through text or images alone. Interactive experiences allow students to observe

and directly experience scientific phenomena, which deepens their understanding. For example, in physics education, students can observe simulations of object motion or electromagnetic experiments in a highly detailed virtual environment (Rosli & Ishak, 2024). Second, Engagement and Motivation in Learning: Research shows that the use of these technologies enhances student engagement in the learning process. More engaging and dynamic activities, such as exploring virtual worlds or manipulating digital objects, motivate students to actively participate in learning and increase their interest in studying science (Villena-Taranilla et al., 2025). Students also report higher motivation levels when learning with these technologies compared to conventional methods. Lastly, Personalized and Flexible Learning: Immersive technologies enable more personalized learning, where students can choose the pace and types of experiments they wish to conduct. This is particularly beneficial for students with different learning styles, offering them the opportunity to learn in a way that best meets their needs (Yang et al., 2024).

Virtual laboratories and immersive technologies such as VR and AR are both widely used in science education, but they have distinct differences. Virtual laboratories focus on simulating science experiments in a digital environment, allowing students to conduct experiments without physical risks, enabling them to repeat experiments, alter variables, and observe different outcomes (Potkonjak et al., 2016). These laboratories are computer-based, where students interact with software interfaces on a screen. In contrast, immersive technologies like VR offer a deeper experience by creating fully immersive 3D environments, while AR enhances the real world by overlaying digital elements, providing a more interactive and realistic experience for students (Calvert & Abadia, 2020; Papanastasiou et al., 2019). Both technologies complement each other, as virtual laboratories are ideal for structured experiment simulations and data exploration, while VR and AR offer more direct, immersive interactions with the concepts being taught. A combination of both approaches provides a comprehensive learning experience, where virtual labs are used for practical experiments, and AR/VR technologies help in exploring visual and immersive concepts (García-Robles et al., 2024).

The implementation of virtual laboratories and immersive technologies in science education is not without its challenges. First, technology limitations: Many schools and universities struggle to provide the necessary hardware, such as VR headsets or AR devices, as well as compatible software. Budget constraints often serve as a major barrier to adopting these technologies (Alalwan et al., 2020). Second, teacher training and competence: To effectively utilize these technologies, teachers require proper training and professional support. Without adequate training, these technologies may not be used optimally, potentially reducing their effectiveness in teaching (McKnight et al., 2016).

CONCLUSION

The integration of virtual laboratories and immersive technologies such as VR and AR into science education offers significant potential to enhance learning experiences. These technologies provide students with interactive, engaging, and risk-free platforms to explore scientific concepts, facilitating a deeper understanding of complex phenomena. Virtual laboratories enable students to conduct experiments repeatedly, modify variables, and observe outcomes, while immersive technologies immerse them in 3D environments or overlay digital elements onto the real world, fostering more meaningful learning. Additionally, the use of these technologies in science

education not only boosts student engagement and motivation but also supports personalized learning by catering to diverse learning styles.

Challenges such as limited infrastructure, high costs, and the need for teacher training remain significant barriers to widespread implementation. Many schools, particularly in developing countries, face difficulties in providing the required hardware and software. Moreover, educators need adequate training and professional development to integrate these technologies effectively into their teaching practices. Despite these challenges, the benefits of virtual laboratories and immersive technologies in enhancing the quality of science education are undeniable, and further research is essential to overcome these barriers and maximize their potential in the classroom.

REFERENCES

- Adiyono, A., Hayat, E. W., Oktavia, E. D., & Prasetyo, N. T. (2024). Learning interaction in the digital era: Technological innovations and education management strategies to enhance student engagement. *Journal of Research in Instructional*, 4(1), 205–221.
- Ahmad, T. (2020). Scenario based approach to re-imagining future of higher education which prepares students for the future of work. *Higher Education, Skills and Work-Based Learning*, 10(1), 217–238.
- Akinradewo, O., Hafez, M., Aliu, J., Oke, A., Aigbavboa, C., & Adekunle, S. (2025). Barriers to the Adoption of Augmented Reality Technologies for Education and Training in the Built Environment: A Developing Country Context. *Technologies*, 13(2), 62. In Press
- Alalwan, N., Cheng, L., Al-Samarraie, H., Yousef, R., Ibrahim Alzahrani, A., & Sarsam, S. M. (2020). Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective. *Studies in Educational Evaluation*, 66, 100876. <https://doi.org/https://doi.org/10.1016/j.stueduc.2020.100876>
- Al-Ansi, A. M., Jaboob, M., Garad, A., & Al-Ansi, A. (2023). Analyzing augmented reality (AR) and virtual reality (VR) recent development in education. *Social Sciences & Humanities Open*, 8(1), 100532.
- AlGerafi, M. A. M., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the potential: A comprehensive evaluation of augmented reality and virtual reality in education. *Electronics*, 12(18), 3953.
- Ali, N., Ullah, S., & Khan, D. (2022). Interactive laboratories for science education: A subjective study and systematic literature review. *Multimodal Technologies and Interaction*, 6(10), 85.
- Alnagrat, A. J. A., Ismail, R. C., & Idrus, S. Z. S. (2022). The Opportunities and challenges in virtual reality for virtual laboratories. *Innovative Teaching and Learning Journal*, 6(2), 73–89.
- Bogusevski, D., Muntean, C., & Muntean, G.-M. (2020). Teaching and learning physics using 3D virtual learning environment: A case study of combined virtual reality and virtual laboratory in secondary school. *Journal of Computers in Mathematics and Science Teaching*, 39(1), 5–18.
- Brown, C. E., Almuny, D., Williams, M. K., Whaley, B., & Hyslop, R. M. (2021). Visualizing molecular structures and shapes: A comparison of virtual reality, computer simulation, and traditional modeling. *Chemistry Teacher International*, 3(1), 69–80.

- Calvert, J., & Abadia, R. (2020). Impact of immersing university and high school students in educational linear narratives using virtual reality technology. *Computers & Education*, 159, 104005. <https://doi.org/https://doi.org/10.1016/j.compedu.2020.104005>
- Caño de las Heras, S., Kensington-Miller, B., Young, B., Gonzalez, V., Krühne, U., Mansouri, S. S., & Baroutian, S. (2021). Benefits and challenges of a virtual laboratory in chemical and biochemical engineering: Students' experiences in fermentation. *Journal of Chemical Education*, 98(3), 866–875.
- Christopoulos, A., Conrad, M., & Shukla, M. (2018). Increasing student engagement through virtual interactions: How? *Virtual Reality*, 22(4), 353–369.
- Dargan, S., Bansal, S., Kumar, M., Mittal, A., & Kumar, K. (2023). Augmented reality: A comprehensive review. *Archives of Computational Methods in Engineering*, 30(2), 1057–1080.
- Dasopang, M. D. (2021). Effectivity of interactive multimedia with theocentric approach to the analytical thinking skills of elementary school students in science learning. *Premiere Educandum: Jurnal Pendidikan Dasar Dan Pembelajaran*, 11(2), 215–226.
- Fadillah, Z. I. (2024). Pentingnya pendidikan stem (sains, teknologi, rekayasa, dan matematika) di abad-21. *JSE Journal Sains and Education*, 2(1), 1–8.
- Fisher, M. M., & Baird, D. E. (2020). Humanizing user experience design strategies with NEW technologies: AR, VR, MR, ZOOM, ALLY and AI to support student engagement and retention in higher education. In *International perspectives on the role of technology in humanizing higher education* (pp. 105–129). Emerald Publishing Limited.
- Fitrianto, I., & Saif, A. (2024). The role of virtual reality in enhancing Experiential Learning: a comparative study of traditional and immersive learning environments. *International Journal of Post Axial: Futuristic Teaching and Learning*, 97–110.
- García-Robles, P., Cortés-Pérez, I., Nieto-Escámez, F. A., García-López, H., Obrero-Gaitán, E., & Osuna-Pérez, M. C. (2024). Immersive virtual reality and augmented reality in anatomy education: A systematic review and meta-analysis. *Anatomical Sciences Education*, 17(3), 514–528. <https://doi.org/10.1002/ase.2397>
- Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, 3, 275–285.
- Hariyono, H. (2023). Penggunaan teknologi augmented reality dalam pembelajaran ekonomi: Inovasi untuk meningkatkan keterlibatan dan pemahaman siswa. *JIIP-Jurnal Ilmiah Ilmu Pendidikan*, 6(11), 9040–9050.
- Heradio, R., De La Torre, L., Galan, D., Cabrerizo, F. J., Herrera-Viedma, E., & Dormido, S. (2016). Virtual and remote labs in education: A bibliometric analysis. *Computers & Education*, 98, 14–38.
- Iskandar, A., Winata, W., Kurdi, M. S., Sitompul, P. H. S., Kurdi, M. S., Nurhayati, S., Hasanah, M., Arisa, M. F., & Haluti, F. (2023). Peran teknologi dalam dunia pendidikan. *Yayasan Cendekiawan Inovasi Digital Indonesia*.
- Kuhail, M. A., ElSayary, A., Farooq, S., & Alghamdi, A. (2022). Exploring immersive learning experiences: A survey. *Informatics*, 9(4), 75.
- Liberatore, M. J., & Wagner, W. P. (2021). Virtual, mixed, and augmented reality: a systematic review for immersive systems research. *Virtual Reality*, 25(3), 773–799.

- Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers & Education*, 95, 174–187.
- Liu, R., Wang, L., Lei, J., Wang, Q., & Ren, Y. (2020). Effects of an immersive virtual reality-based classroom on students' learning performance in science lessons. *British Journal of Educational Technology*, 51(6), 2034–2049.
- McKnight, K., O'Malley, K., Ruzic, R., Horsley, M. K., Franey, J. J., & Bassett, K. (2016). Teaching in a Digital Age: How Educators Use Technology to Improve Student Learning. *Journal of Research on Technology in Education*, 48(3), 194–211. <https://doi.org/10.1080/15391523.2016.1175856>
- Mohamed Shaffril, H. A., Samsuddin, S. F., & Abu Samah, A. (2021). The ABC of systematic literature review: the basic methodological guidance for beginners. *Quality & Quantity*, 55, 1319–1346.
- Papanastasiou, G., Drigas, A., Skianis, C., Lytras, M., & Papanastasiou, E. (2019). Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills. *Virtual Reality*, 23(4), 425–436. <https://doi.org/10.1007/s10055-018-0363-2>
- Pellas, N., Kazanidis, I., & Palaigeorgiou, G. (2020). A systematic literature review of mixed reality environments in K-12 education. *Education and Information Technologies*, 25(4), 2481–2520.
- Pellas, N., Mystakidis, S., & Kazanidis, I. (2021). Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature. *Virtual Reality*, 25(3), 835–861.
- Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education*, 95, 309–327. <https://doi.org/https://doi.org/10.1016/j.compedu.2016.02.002>
- Pramanik, S. (2024). Immersive Innovations: Exploring the Use of Virtual and Augmented Reality in Educational Institutions. In *Augmented Reality and the Future of Education Technology* (pp. 66–85). IGI Global.
- Rokhsaritalemi, S., Sadeghi-Niaraki, A., & Choi, S.-M. (2020). A review on mixed reality: Current trends, challenges and prospects. *Applied Sciences*, 10(2), 636.
- Rosli, R., & Ishak, N. A. (2024). Integration of Virtual Labs in Science Education: A Systematic Literature Review. *Jurnal Pendidikan Sains Dan Matematik Malaysia*, 14(1), 81–103.
- Salar, R., Arici, F., Caliklar, S., & Yilmaz, R. M. (2020). A model for augmented reality immersion experiences of university students studying in science education. *Journal of Science Education and Technology*, 29, 257–271.
- Sauer, P. C., & Seuring, S. (2023). How to conduct systematic literature reviews in management research: a guide in 6 steps and 14 decisions. *Review of Managerial Science*, 17(5), 1899–1933.
- Tene, T., Marcatoma Tixi, J. A., Palacios Robalino, M. de L., Mendoza Salazar, M. J., Vacacela Gomez, C., & Bellucci, S. (2024). Integrating immersive technologies with STEM education: a systematic review. *Frontiers in Education*, 9, 1410163.
- Timotheou, S., Miliou, O., Dimitriadis, Y., Sobrino, S. V., Giannoutsou, N., Cachia, R., Monés, A. M., & Ioannou, A. (2023). Impacts of digital technologies on education and factors

- influencing schools' digital capacity and transformation: A literature review. *Education and Information Technologies*, 28(6), 6695–6726.
- Valverde-Berrocso, J., Garrido-Arroyo, M. del C., Burgos-Videla, C., & Morales-Cevallos, M. B. (2020). Trends in educational research about e-learning: A systematic literature review (2009–2018). *Sustainability*, 12(12), 5153.
- Van Dinter, R., Tekinerdogan, B., & Catal, C. (2021). Automation of systematic literature reviews: A systematic literature review. *Information and Software Technology*, 136, 106589.
- Villena-Taranilla, R., Diago, P. D., & Colomer Rubio, J. C. (2025). Virtual Reality as a Pedagogical Tool: Motivation and Perception in Teacher Training for Social Sciences and History in Primary Education. *Education Sciences*, 15(4), 493. <https://doi.org/10.3390/educsci15040493> In Press
- Xiong, J., Hsiang, E.-L., He, Z., Zhan, T., & Wu, S.-T. (2021). Augmented reality and virtual reality displays: emerging technologies and future perspectives. *Light: Science & Applications*, 10(1), 216.
- Yang, C., Zhang, J., Hu, Y., Yang, X., Chen, M., Shan, M., & Li, L. (2024). The impact of virtual reality on practical skills for students in science and engineering education: a meta-analysis. *International Journal of STEM Education*, 11(1), 28. <https://doi.org/10.1186/s40594-024-00487-2>
- Yılmaz, A. (2021). The effect of technology integration in education on prospective teachers' critical and creative thinking, multidimensional 21st century skills and academic achievements. *Participatory Educational Research*, 8(2), 163–199.
- Yılmaz, Ö. (2023). The role of technology in modern science education. *Current Research in Education*; Baltacı, Ö., Ed.; Özgür Publications: Gaziantep, Turkey, 6, 35–60.
- Zhai, X. (2021). Practices and theories: How can machine learning assist in innovative assessment practices in science education. *Journal of Science Education and Technology*, 30(2), 139–149.